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GRAPHITE - METAL COMPOSITES
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I. INTRODUCTION AND SUMMARY

This program was originally conceived to investigate liquid phase sintering in graphite-metal composites during hot pressing at elevated (2800° - 3000°C) temperatures. The first year's studies[1] revealed that a strong bond is obtained by formation, diffusion, and subsequent recrystallization of a carbide-carbon eutectic phase in selected composites. Flexural strengths of greater than 14,000 psi were exhibited by graphite systems containing niobium carbide or hafnium carbide at both temperature and 2000°C.

The purpose of this year's work is to extend the compositional studies into higher metal contents and to fully characterize the properties of composites which exhibit the greatest potential for high temperature applications. The metal phases with which we are most concerned are niobium, tantalum, hafnium, zirconium, titanium, and molybdenum. Parameters which are being investigated in these systems include type and particle size of raw materials, and relationship between processing and carbide-carbon eutectic temperatures.

During this period, compositional studies have included the effect of graphite source material on the properties

of Mo-C composites. Investigations of other systems incorporating tungsten, vanadium, hafnium, tantalum, niobium and zirconium as the metal constituent were conducted. Studies of time-temperature relationships in processing have been initiated. Measurements of electrical resistivity have shown a definite correlation with flexural strength.

II. DISCUSSION

A. Effect of Graphite Source

The following carbonaceous materials were examined to determine the effect of type and shape of graphite source material on densification and bonding. The powders (all of less than 44_{μ} particle size) which were examined are:

1. Calcined petroleum coke (CPC) - has been the graphite source in past experiments. Particles are flat and plate-like and of high surface area.
2. Calcined Gilsonite coke (GC) - particles are spherical.
3. Synthetic resin coke (RC) - a highly cross linked structure with irregularly shaped particles.
4. Synthetic graphite (BB) - an initial graphitic structure material with particles of a shape similar to that for CPC.

These four carbons were hot pressed without additives at 3000°C under 3000 psi. Data in Table I show the densities and flexural strengths of the various bodies. Highest density was exhibited by CPC. The somewhat low density of RC can be attributed to limited graphitization and the true density of 1.52g/cc for this material. Bonding was quite poor for all systems as seen by the flexural strengths of ~1000 psi. The GC samples in particular were quite fragile. Microphotographs

of the various systems are presented in Figure 1. Considerable porosity is seen to exist in all of the bodies.

Examination by x-ray diffraction techniques revealed that CPC and BB were well graphitized and highly ordered. The GC sample showed a somewhat lesser degree of graphitization. The broadness of the diffraction pattern peaks and poor resolution indicated limited ordering in the RC. This is to be expected since RC is a "glassy" carbon with a high degree of cross linking which prevents easy graphitization.

Each of the four carbon sources were mixed with 50wt% molybdenum and again processed at 3000°C. The strength data in Table I clearly shows the improved bonding attainable with the formation of the Mo_2C-C eutectic (~2600°C) and subsequent recrystallization of the liquid phase. Highest strengths were exhibited by the CPC composition. The spherical cokes, i.e., GC and RC, achieved lower degree of bonding than "platy" CPC and BB.

Microstructures of the four systems appear in Figure 2. It is interesting to note the relative size of molybdenum carbide particles. The finest structure and dispersion are in the RC and BB systems (Figures 2c and 2d), suggesting a more homogeneous distribution of the carbide-carbon eutectic phase. However, a relatively high degree of porosity exists in the RC system as seen in Figure 2c, and this may be the reason for its limited bonding.

X-ray diffraction studies showed that all of the Mo-containing systems were highly graphitized and ordered. With the addition of molybdenum, the resin coke system developed a well defined ordering. This can be due to either or both of the following mechanisms. First, the molybdenum in forming the carbide, would react with the more disordered carbon and permit easier graphitization of the less disordered material.

Secondly, the formation of the carbide-carbon eutectic liquid would permit greater densification and ordering.

The experiments show that plate-like carbon particles are preferable for attaining good densification and bonding in hot pressed metal-graphite composites. Calcined petroleum coke is a good choice in this respect. Liquid phase sintering is clearly available with the addition of molybdenum, and graphitization of any carbon material would appear feasible through such metal addition.

B. Compositional Studies

1. Nb-C

The potential exhibited by the niobium system in the first year's program (16,000 psi room temperature flexural strength) has made it a prime candidate for additional study. A series of compositions ranging up to 84wt% niobium were prepared at 3000°C and a pressure of 3000 psi. Property data are presented in Table II.

At the 50 and 65wt% metal content strengths were dissappointingly low although high densities were achieved. Even the values for the 65wt% compositions were only one-half of those attained earlier for 50wt% composites. The microstructure shown in Figure 3 reveals fairly large, oriented carbide particles. A completely different structure was exhibited by the 16,000 psi, 50wt% Nb samples (Figure 4). For the stronger material, the particles are much smaller and their shape suggests melting and recrystallization.

As reported in Report No. IITRI-G6003-F4, difficulties in pyrometry in the first year's program may have lead to processing at higher temperatures than measured, and it is quite possible that earlier high strengths were attained by exceeding the nominal temperature of 3000°C to a closer approach of the

NbC-C eutectic temperature, 3250°C. In the present experiments, the 3000°C processing temperature is adhered to more accurately, thus reducing carbide diffusion and limiting strong bonding. Additional niobium experiments will be conducted at a fabrication temperature of 3100°C or possibly higher to verify the reasons for the high strengths initially observed.

At the higher metal contents, fairly high strengths were achieved. These compositions represent the hypereutectic (80wt%), eutectic (81.3wt%), and hypoeutectic (84.0wt%). The existence of a graphite phase is evident in microstructural examination as shown in Figure 5, indicating that carbide-carbon eutectic formation was quite limited.

For materials prepared by arc melting and casting techniques in the zirconium and titanium systems, high strengths have been shown in the range of compositions from the pure carbide to carbide-graphite, with a rapid drop-off in the hypereutectic (or higher graphite content) region.[2] For the Ti-C system, this steep loss in room temperature flexural strength occurred within a range of perhaps 2wt% going from 30,000 (75.5wt% Ti) to 10,000 psi (73.5wt% Ti). Our work with hot pressed composites in the niobium system suggests no such rapid drop-off in strength with increasing graphite content, as indicated by a room temperature strength of 16,000 psi at 50wt% niobium. The severe loss in strength in the hypereutectic region for arc cast materials may be due to the growth of long graphite platelets which can act as flaws.

At 2000°C slightly higher strengths were exhibited by all specimens. This is somewhat surprising for the >80wt% compositions since the dominant phase as seen from the photomicrographs (Figure 5) is the carbide which by itself would show a much lower strength[3] at 2000°C. A possible explanation is that at room temperature, tensile forces prevail in the carbide phase, brought on by difference in thermal expansion on fabri-

cation cooling. However, these detrimental forces tend to disappear as the material is heated so that at 2000°C, a body which is relatively stress free exists.

The high strengths exhibited by these composites at 2000°C is indeed promising. Tests at even higher temperatures (2500 - 2800°C) will be conducted to determine their usefulness for environmental conditions which these metal-graphite bodies may encounter in actual application.

C. Other Systems

Other metal additions which have been investigated during this period are tungsten, vanadium, hafnium, tantalum, and zirconium. Data for these compositions appear in Table III. Tungsten (Group VI-A) and vanadium (Group V-A) are two materials which hitherto had not been studied; 50wt% compositions of each have been included for examination as type comparisons. Excellent strengths were exhibited by the tungsten composites. Examination of the microstructure (Figure 6) shows a fine dispersion of carbide. The rounded shape of these particles suggests that melting and recrystallization had occurred as would be expected from the low melting point (2776°C) of WC. In the with-grain direction, strength at 2000°C was virtually the same while creep was exhibited in the across-grain direction.

During the processing of the vanadium composition, gross extrusion of metal around the punches was observed. This is probably due to the fact that the processing temperature of 3000°C was 350°C higher than the melting point of VC (2650°C) thus yielding a very mobile system. Densities and strengths were relatively low. However, the microstructure (Figure 7) does not show the extensive porosity suggested by the % theoretical density value shown in Table III, and the low density is probably due to an actual lower metal content in the finished billet than initially incorporated. Again, melting and

recrystallization is suggested by the size and shape of the carbide phase. For both the tungsten and vanadium systems, a lower processing temperature is needed for obtaining composites of optimum properties.

Increased metal content to 65wt% hafnium produced a very dense system. However, the billet itself exhibited a dense outer border with a somewhat porous center. Although this did not show up in density measurements, strength measurements showed that the edges were clearly stronger than the center. The microstructure in Figure 8 reveals orientation of carbide grains; actual melting to any extent is doubtful. A slight increase in strength was evident at 2000°C.

Composites for the tantalum system were prepared using tantalum metal instead of the carbide used in earlier studies. It was felt that in forming the carbide, the metal might form a better bond with the graphite matrix. However, the results at both the 50 and 65wt% metal levels indicate poor bonding and it is doubtful if any diffusion of carbide or carbide-graphite has occurred. At this processing temperature, no difference is evident using either the metal or the carbide as a raw constituent. Fairly high porosity and carbide grains undiminished in size are seen in the 50wt% Ta bodies (Figure 9); the 65wt% composite is quite similar in appearance. Recent work has established the TaC-C eutectic to be 3445±50°C[4]; similar to the niobium system, a higher processing temperature is required. Areas which require further investigation are ternary systems such as Ta-Hf-C which has a lower melting point than the Ta-C system.

The zirconium system exhibited only limited bonding and densification in the first year's program (~5000 psi). However, the ZrC-C eutectic temperature of 2850°C would make it seem ideal for liquid phase sintering at processing temperatures of 2800° or 3000°C, and thus new composites containing

50wt% and 80.7wt% Zr (eutectic) were hot pressed at 2800°C. As the results show, densification and bonding were considerably higher for the present 50wt% Zr experiment showing that the earlier strength values of ~5000 psi were anomalously low. Figure 10 shows the carbide grains to be somewhat oriented with little evidence of any extensive melting.

Flexural strength of the eutectic (80.7wt% Zr) composition were somewhat low (17,000 psi) compared to the literature value of 20,000 psi.[3] However, like the eutectic composition of NbC-C, an increase in strength to 22,000 psi exists at 2000°C. This increase may be attributed to the reasons advanced for the niobium composites, i.e., stress relief at 2000°C. The microstructure (Figure 11) shows free graphite. Carbide-carbon solution to yield the eutectic structure appears limited.

The compressive strength of arc cast zirconium-graphite eutectic composition at 2000°C is more than 80% lower than at room temperature; that of a hypereutectic is ~60% lower.[2] Our hot pressed bodies of eutectic composition show a flexural strength of 20,000 psi at 2000°C whereas the compressive strength (which for graphite is about 2 times the flexural strength) of arc cast composites is 10,000 psi at 2000°C. Thus, a 2000°C strength ratio of 4:1 is indicated for hot pressed composites as compared to those prepared by arc melting and casting. As in the niobium system, the high strength for a 50wt% Zr body (13,000 psi) suggest more of a linear relationship of strength to graphite content, and a drastic loss in properties at the hypereutectic composition is not expected.

The zirconium bodies processed at 3000°C were of low density and exhibited poor bonding. The data for these bodies (50wt% and 65wt%) is similar to that obtained in the earlier program. Considerable extrusion of metal was observed to have occurred in examination of the molds. The importance of

processing at temperatures which do not exceed the carbide-carbon eutectic by a great amount, has been evidenced by the zirconium experiments in which processing below the ZrC-C eutectic (2850°C) produced dense, strong bodies, whereas loss of metal and poor bonding resulted from fabrication at 3000°C. This condition was also observed for the vanadium system. However, results for the Group VI-A metals, tungsten, and molybdenum, did not appear to show any strong deleterious effects on strength, of processing at 3000°C which is higher than the melting points of WC (2785°C) or Mo_2C (2600°C).

D. Resistivity vs Strength

Knudsen[5] has given the explanation of the exponential relationship between mechanical strength and porosity in ceramic materials, which had been established on a semi-empirical base earlier by Ryshkewitch[6], by showing that the effective contact area for any spatial arrangement of sphere like particles is a logarithmic function of the porosity. The porosity range within which this relation holds true depends on the packing structure and extends from 0 to about 40% porosity for a close packed cubic arrangement. Since the strength of a porous material is a linear function of the effective cross section, it follows that the strength also is a logarithmic function of porosity. It has also been verified experimentally by Rubin[7] that the electrical resistivity of ceramic materials is an exponential function of the porosity for the same reason as in the above case. Thus, both strength and resistivity are linear functions of the effective cross section of a porous material which itself is a logarithmic function of the porosity. One would, therefore, expect a linear relationship between strength and electrical resistivity in single phase, ceramic materials. This relationship would no longer explicitly contain the porosity,and strength should be predictable from measurements of electrical resistivity independent of porosity.

A linear strength - resistivity relationship has been found to hold true for metal carbide-graphite composite materials hot pressed in this laboratory, as shown in Figures 12 - 16. The strength measurements have been discussed in earlier reports. The electrical resistivity measurements have been done by a four-terminal method. Sample bars, 0.4 cm^2 cross section [$(\frac{1}{4}")^2$] and about 5 cm (2") long, were used. Silver electrodes were applied at both ends and a constant current of 10mA was passed through each sample by regulating the resistance in series with a battery. The potential drop in the direction of the current and near the center portion of the sample was measured several times, i.e., with a two contact voltage probe, (the distance between the contacts being 1 cm) and a Hewlett Packard 425A-type microvolt meter. Values for at least two of the four plane surfaces were averaged. The results are plotted in figures 12 through 16. The linear relationship between conductivity and strength holds fairly well for the systems investigated. It appears then that the highest possible strength obtainable in a particular composite system can be calculated from resistivity and strength measurements on two compositions, knowing the resistivity of the pure carbide. In this approach only the mechanically stronger phase, which is also the electrically better conducting phase, was considered and the graphite phase together with physical voids were treated as porosity. The slope of the conductivity-strength relationship, which is close to 0.5 for the systems studied, is considered to provide a sensitive measure of the strengthening mechanism in these composite systems and should reflect the effect of processing conditions on the microstructure. In order to check this hypothesis, reduced coordinates will be used and quantitative metallographic examinations will be conducted.

E. Time-Temperature Relationships in Processing

Experiments have been performed to determine the effect of soak time at temperature on the properties of molybdenum-graphite composites. Two processing temperatures, 2800° and 3000°C, and two soak times, 0 and 1 hours, were introduced as variables for 50wt% Mo compositions. The results are summarized in Table IV.

The effects of a one-hour soak, are as follows:

1. No significant change in room temperature strength is apparent.
2. Densities are somewhat lower after a one-hour soak. This may be due to loss of metal, resulting in composites of <50wt% Mo.
3. Anisotropy increases after a one-hour soak, revealing a higher degree of ordering.

The higher processing temperature, i.e., 3000° vs 2800°C, resulted in bodies of lower densities and strength. This is probably due to greater loss of metal, an effect also seen after a one-hour soak as listed above.

All samples exhibited strength losses at 2000°C in the W/G direction and creep in the A/G direction. There does appear to be a definite correlation between this loss in strength and both processing temperature and time of soak. As shown in Table IV, retention of strength was better for samples which had been soaked, and also for those fabricated at the higher (3000°C) temperature. Again, the reason may be metal loss since earlier work had shown that composites incorporating lesser amounts of Mo showed higher strengths at 2000°C than at room temperatures, e.g., 30wt% Mo had a room temperature value of 8060 psi and a 2000°C value of 9250 psi. Microstructural examination and quantitative analysis for metal content will be conducted to obtain a clearer analysis of these effects.

III. CONCLUSIONS AND FUTURE WORK

Compositional studies in graphite-metal systems have included examination of graphite source and extension of metal contents up to the eutectic composition. The most significant outcomes of the present work are as follows:

1. The use of flat, platy particles as opposed to spherical cokes yields better bonding in graphite-metal composites. Calcined petroleum coke appears to be a good graphite source for obtaining good densification and bonding.

2. In the Nb-C system, room temperature flexural strengths of greater than 20,000 psi and an increase in strength at 2000°C can be expected for compositions in the eutectic range (80-84wt% Nb). The present experiments also indicate that a higher processing temperature more closely approaching the NbC-C eutectic temperature of 3250°C is necessary for achieving optimum properties.

3. Present work in the zirconium system shows that room temperature strengths in excess of 13,000 psi can be realized at 50wt% Zr. This is in contrast to the 5,000 psi strength indicated in the first year's program. Furthermore, a significant increase in strength (18,000 psi) at 2000°C exists for this system.

4. The processing temperature should not exceed the carbide-carbon eutectic temperature by more than about 50°C, if significant loss of metal is to be avoided. This loss of metal will not only produce

bodies of lower metal content and hence lower strengths, but can also result in metal segregation and gross porosity which will affect bonding deleteriously.

Studies of the ZrC-C eutectic composition (80.7wt% Zr) show that hot-pressed bodies are much stronger at 2000°C than recently developed arc melted and cast composites of similar composition. The latter exhibit a significant loss in compressive strength to 10,000 psi at 2000°C[2] whereas a flexural strength of >20,000 psi exists for our specimens. Furthermore, hot-pressed composites of higher graphite content are considerably stronger than their arc cast counterparts.

Experiments have also shown a direct, linear relationship between flexural strength and electrical conductivity. This relationship appears to be independent of porosity, composition, or fabrication temperature. Thus, the strength is directly relatable to particle-to-particle contact of the carbide and/or carbide-carbon eutectic phase.

Future work will involve continuation of compositional studies investigating the following parameters:

1. Eutectic (carbide-carbon) vs processing temperature.
2. Time-temperature relationships in processing.
3. Effect of incorporating different metal sources such as metal fibers, oxides, and soluble salts.

In addition, high temperature (>2500°C) measurements of physical properties such as compressive creep will be conducted for selected compositions. Also, room temperature stress-strain relationships will be determined.

IV. CONTRIBUTING PERSONNEL AND LOGBOOK RECORDS

Contributing personnel include S. L. Blum, S. A. Bortz, G. Besbekis, and R. Baker. All data are contained in Logbook Nos. C16005, C16010, C16483 and C16487.

Respectfully submitted,
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TABLE I

EFFECT OF GRAPHITE SOURCE MATERIAL ON DENSIFICATION AND BONDING

	No Additives		50 wt% Mo Addition		
Carbon	Density, g/cc	Flexural Strength, psi*	Density, g/cc	Theoretical Density, %	Flexural Strength, psi*
CPC	1.95	1420	2.88	73.5	13,130
GC	1.74	560	2.73	69.6	7660
RC	1.41	1000	2.79	71.1	7570
BB	1.78	1140	2.69	68.6	9550

NOTE: All samples processed at 3000°C - 3000 psi
* In W/G direction

TABLE II

PROPERTIES OF Nb-C COMPOSITES

Niobium Additive		Density,	Theoretical	Flexural Strength, psi*	
Wt%	At%	g/cc	Density, %	Room Temp.	2000°C
50	11.4	3.51	92.9	6100	9100
65	19.4	4.44	93.8	8070	10,800
65	19.4	4.45	93.9	8380	12,810
80	34.1	6.10	96.4	19,130	21.700
81.3	36.4	6.30	96.5	24,190	25,270
84.0	40.6	6.61	94.8	23,200	>24,700

NOTE: All samples processed at 3000°C - 3000 psi
* In W/G direction

TABLE III

PROPERTIES OF METAL-GRAPHITE COMPOSITES

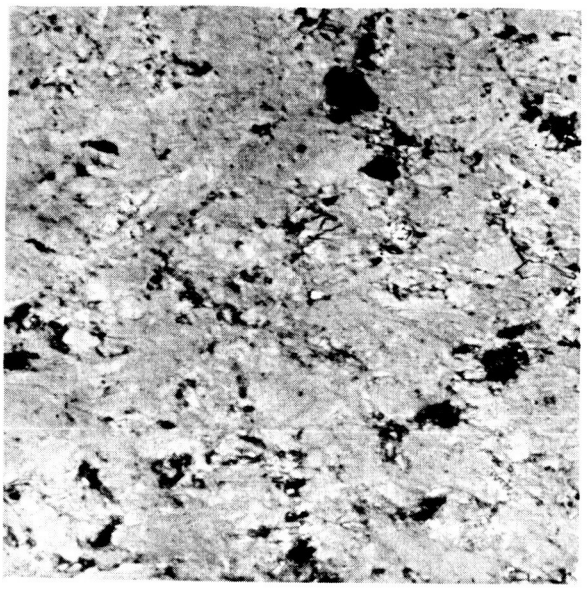
Metal Additives			Pressing	Density	% Theoretical	FLEXURAL STRENGTH, PSI			
						Room Temp		2000°C	
Form	Wt%	At%	Temp °C	g/cc	Density	W/G	A/G	W/G	A/G
W	50	8.3	3000	3.70	88.6	15,100	5030	15,810	Creep
VC	50	20.6	3000	2.29	64.2	4,710		7,200	
HfC	65	11.4	3000	5.00	95.0	10,140		11,810	
Ta	50	8.3	3000	4.01	97.0	2,750		3,810	
Ta	65	11.5	3000	4.97	91.4	3,130	1130	6,450	1870
ZrC	50	11.3	2800	3.29	88.9	13,390		18,750	
ZrC	80.7	35.0	2800	5.57	98.4	16,910		22,340	
ZrC	50	11.3	3000	2.23	59.8	5,810		12,710	
ZrC	65	19.2	3000	2.12	48.4	4,400		7,280	

TABLE IV

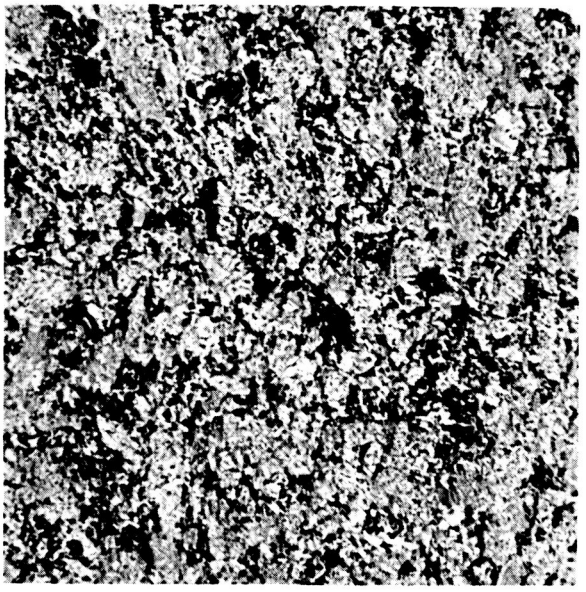
EFFECT OF PROCESSING TEMPERATURE

AND SOAK TIME ON PROPERTIES OF Mo-C

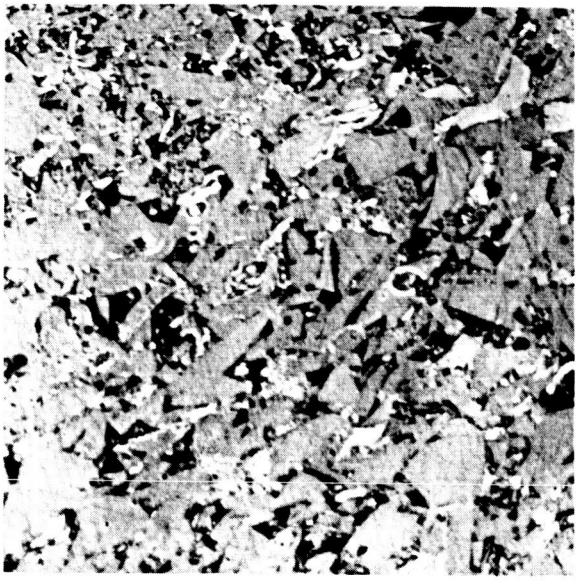
Pressing Temp °C	Soak Time	Density g/cc	FLEXURAL STRENGTH, PSI					% Loss in Strength at 2000 °C
			Room Temperature			2000 °C		
			W/G	A/G	W/G:AG	W/G	A/G	
2800	0	3.11	18,930	6740	2.8	13,840	Creep	26.9
2800	1 hr	2.98	19,150	6390	3.0	14,720	Creep	23.1
3000	0	2.99	17,800	6450	2.8	14,690	Creep	17.5
3000	1 hr	2.76	17,020	5050	3.4	15,380	Creep	9.6



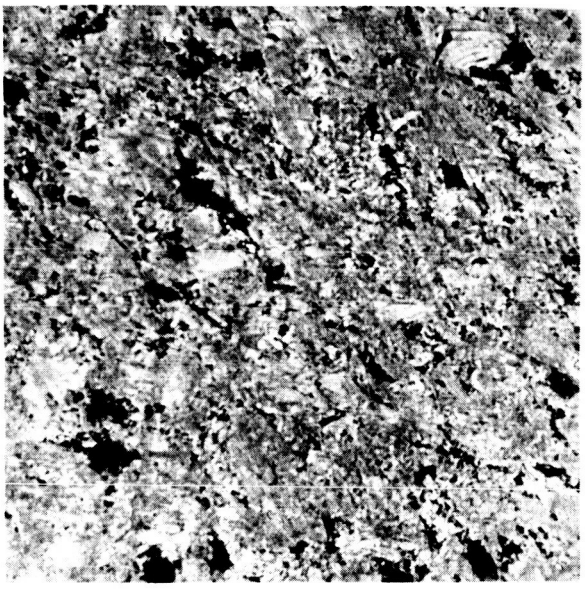
(a) CPC



(b) GC

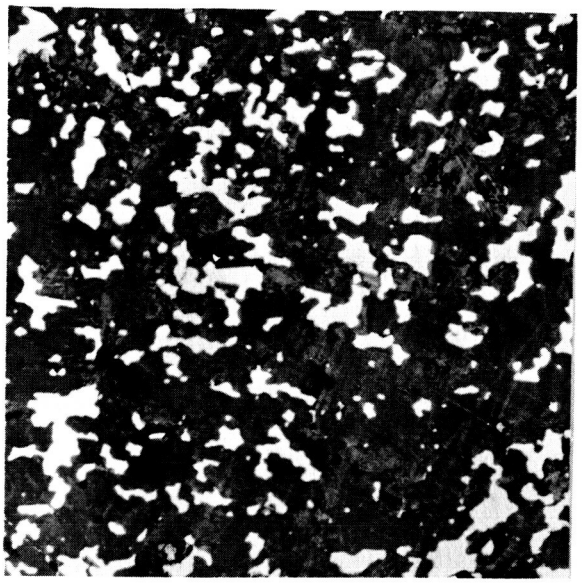


(c) RC

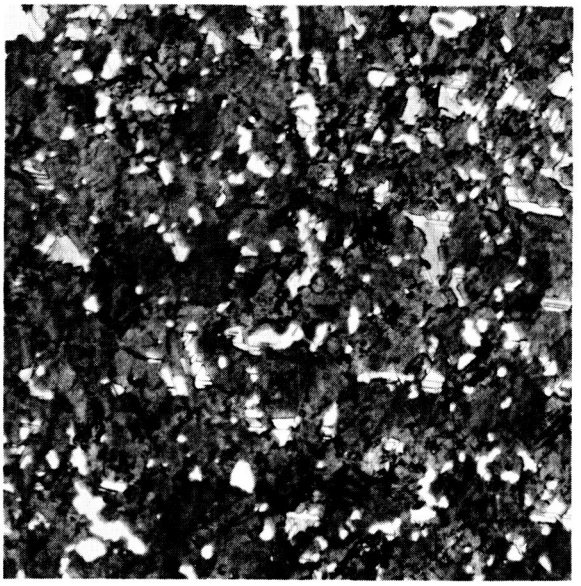


(d) BB

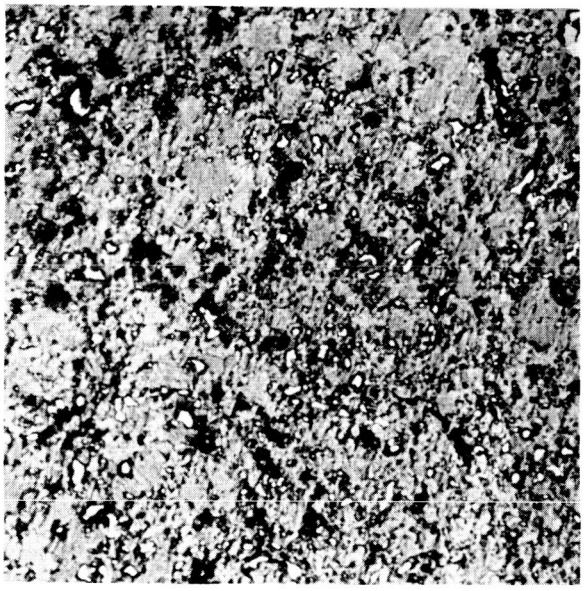
FIG. 1 - MICROSTRUCTURE OF HOT PRESSED GRAPHITE BODIES USING DIFFERENT CARBON SOURCES (320X)
(a) Calcined Petroleum Coke
(b) Calcined Gilsonite Coke
(c) Synthetic Resin Coke
(d) Synthetic Graphite



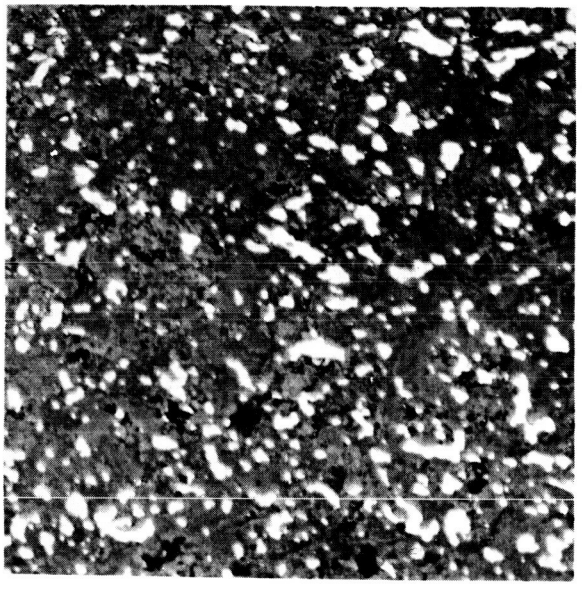
(a) 50 wt% Mo-C (CPC)



(b) 50 wt% Mo-C (GC)



(c) 50 wt% Mo-C (RC)



(d) 50 wt% Mo-C (BB)

FIG. 2 - MICROSTRUCTURE OF 50 WT% Mo-GRAPHITE COMPOSITES INCORPORATING DIFFERENT CARBON SOURCES (320X)

(a) Calcined Petroleum Coke
(b) Calcined Gilsonite Coke
(c) Synthetic Resin Coke
(d) Synthetic Graphite

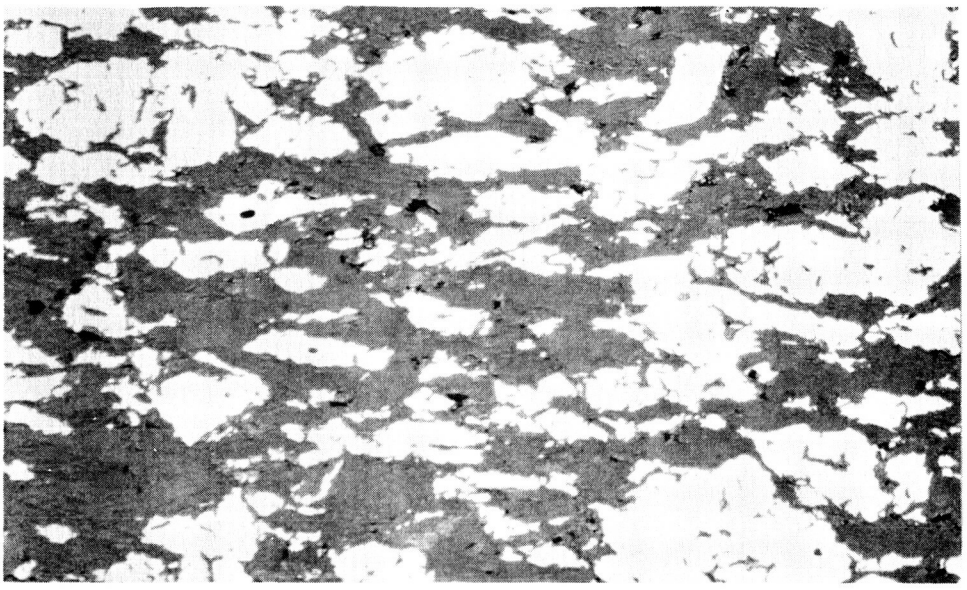
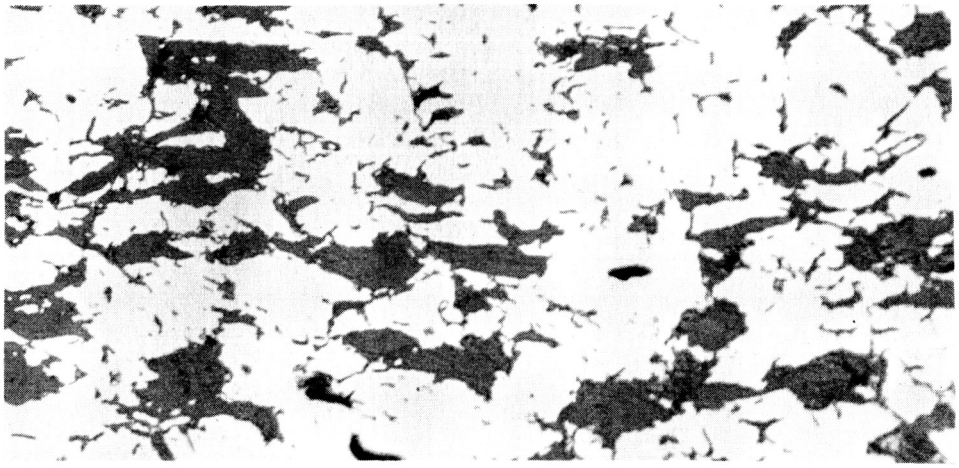
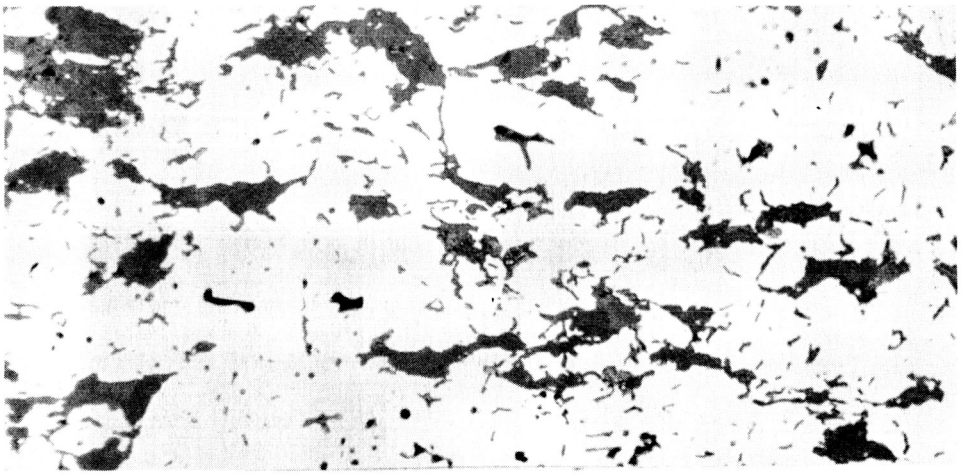


FIG. 3 - MICROSTRUCTURE OF 65 WT% Nb-GRAPHITE PRESSED AT 3000°C (320X)

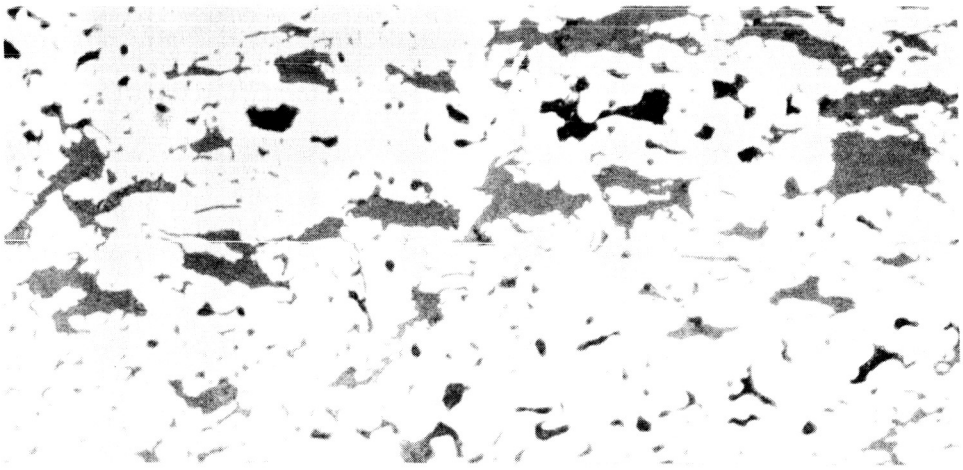
FIG. 4 - MICROSTRUCTURE OF A HIGH STRENGTH (16,000 psi) 50 WT% Nb-GRAPHITE COMPOSITE (320X)



(a)
80.0 wt% Nb



(b)
81.3 wt% Nb



(c)
84.0 wt% Nb

FIG. 5 - MICROSTRUCTURE OF EUTECTIC RANGE Nb-GRAPHITE COMPOSITIONS PRESSED AT 3000°C (320X)
(a) Hypereutectic Composition
(b) Eutectic Composition
(c) Hypoeutectic Composition

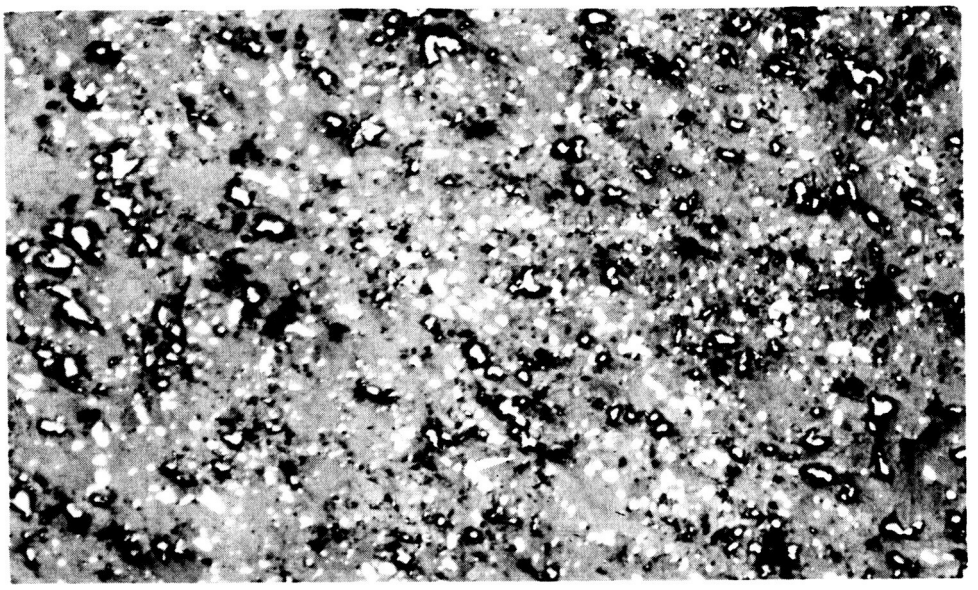


FIG. 6 - MICROSTRUCTURE OF 50 WT% W-GRAPHITE PRESSED AT 3000°C (320X)

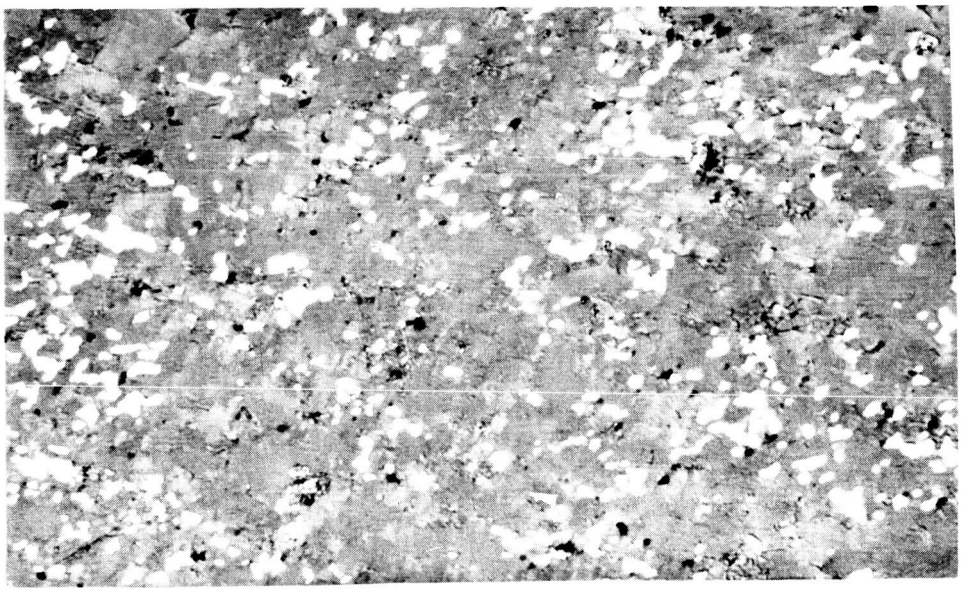


FIG. 7 - MICROSTRUCTURE OF 50 WT% V-GRAPHITE PRESSED AT 3000°C (320X)

FIG. 8 - MICROSTRUCTURE OF 65 WT% Hf-GRAPHITE PRESSED AT 3000°C (320X)

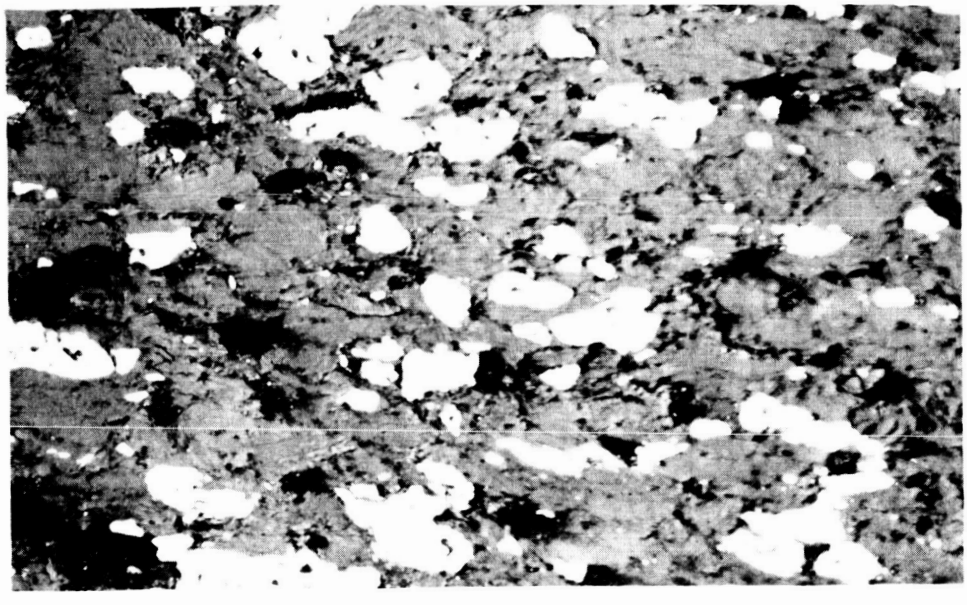


FIG. 9 - MICROSTRUCTURE OF 50 WT% Ta-GRAPHITE PRESSED AT 3000°C (320X)

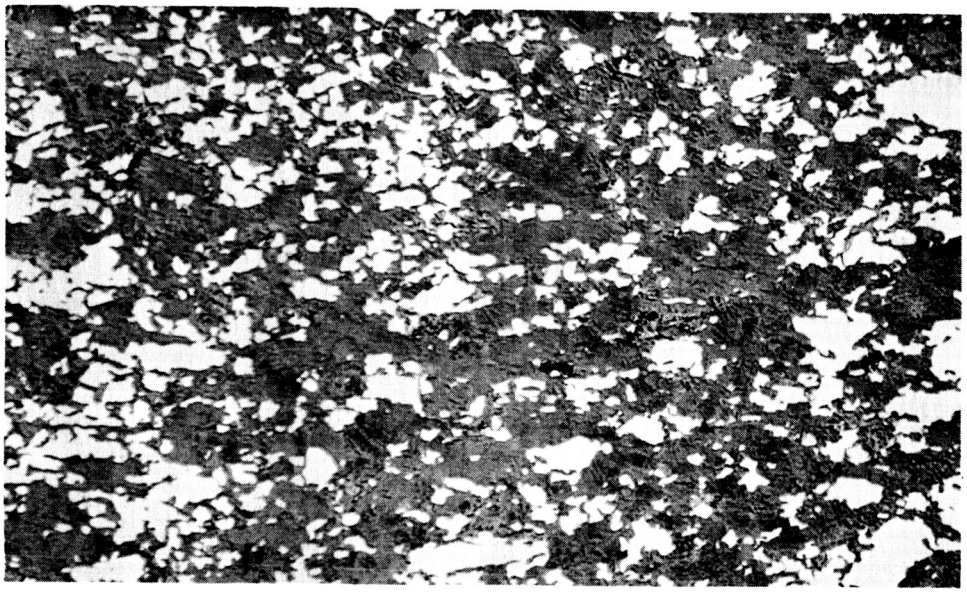


FIG. 10 - MICROSTRUCTURE OF 50 WT% Zr-GRAPHITE PRESSED AT 3000°C (320X)

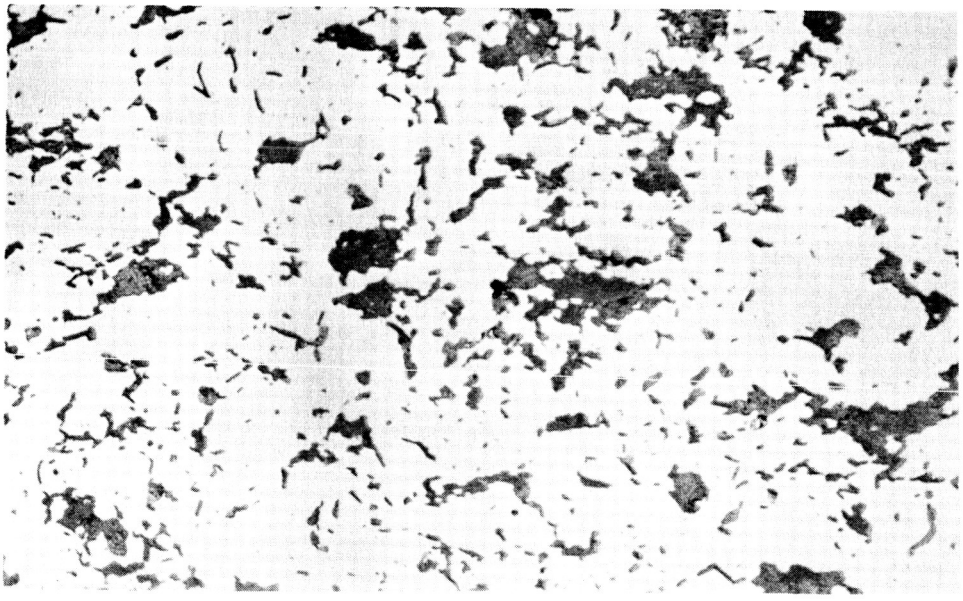


FIG. 11 - MICROSTRUCTURE OF 80.7 WT% Zr-GRAPHITE PRESSED AT 2800°C (320X)

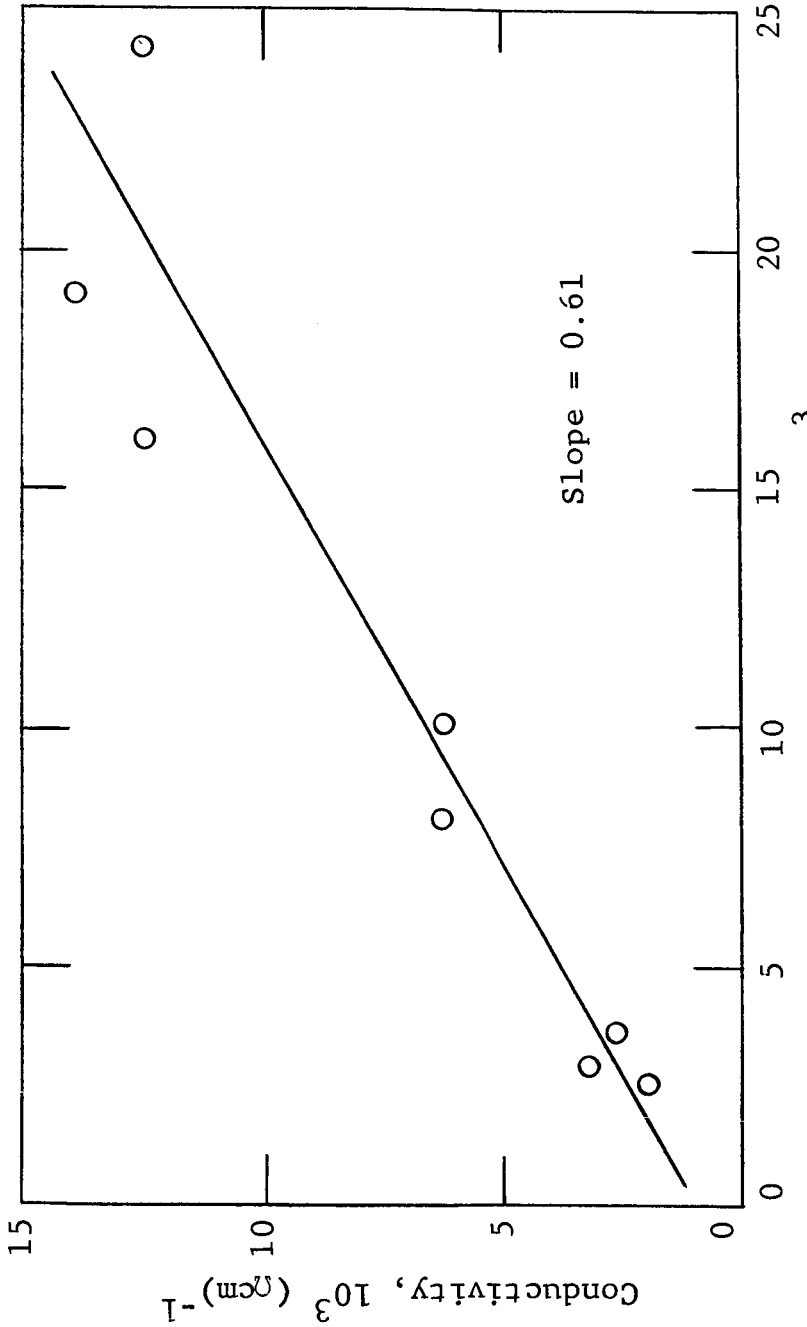


FIGURE 12: ELECTRICAL CONDUCTIVITY AS A FUNCTION OF FLEXURAL STRENGTH FOR NIOBIUM-GRAPHITE COMPOSITES

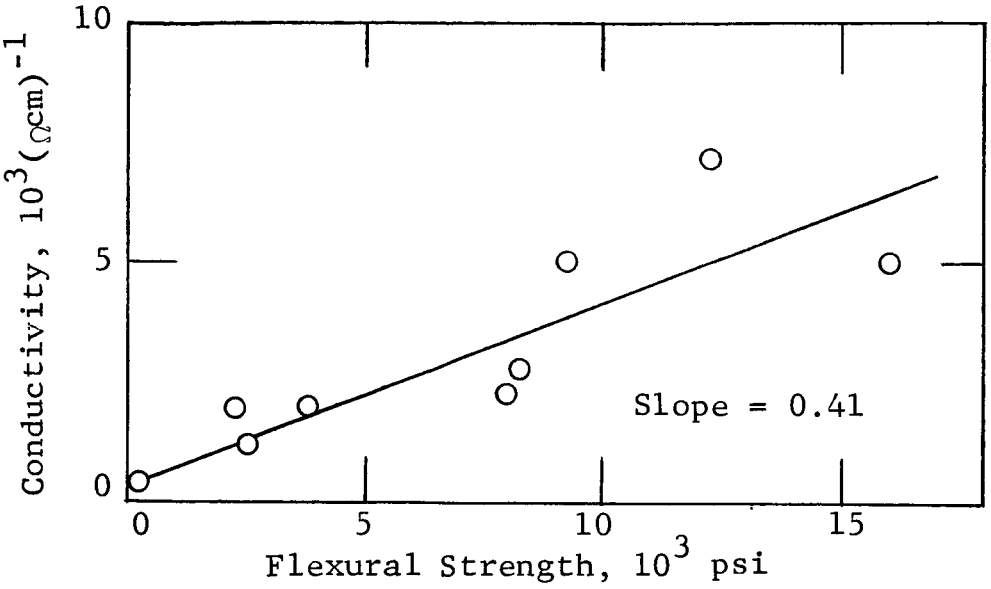


FIGURE 13: ELECTRICAL CONDUCTIVITY AS A FUNCTION OF FLEXURAL STRENGTH FOR HAFNIUM-GRAPHITE COMPOSITES

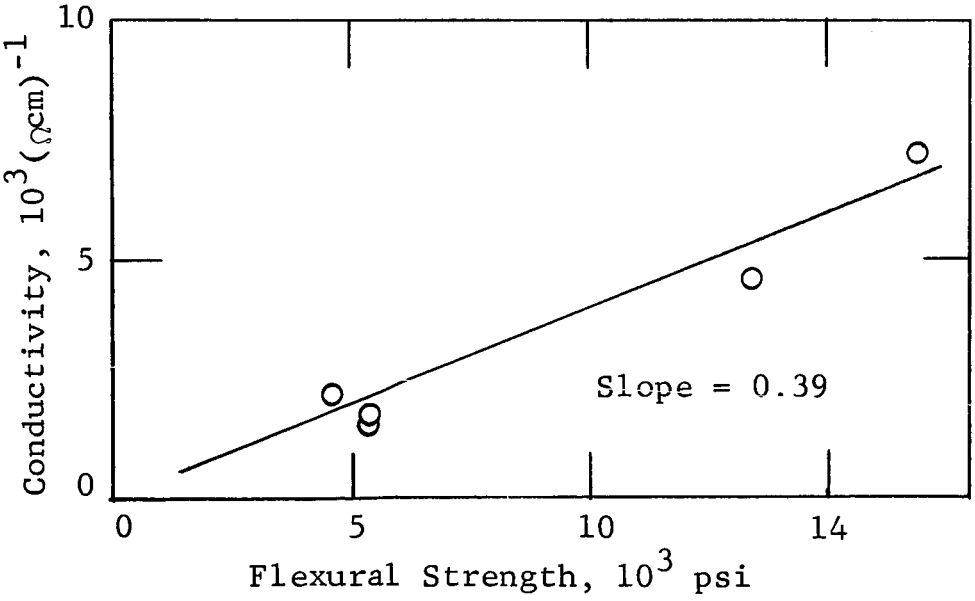


FIGURE 14: ELECTRICAL CONDUCTIVITY AS A FUNCTION OF FLEXURAL STRENGTH FOR ZIRCONIUM-GRAPHITE COMPOSITES

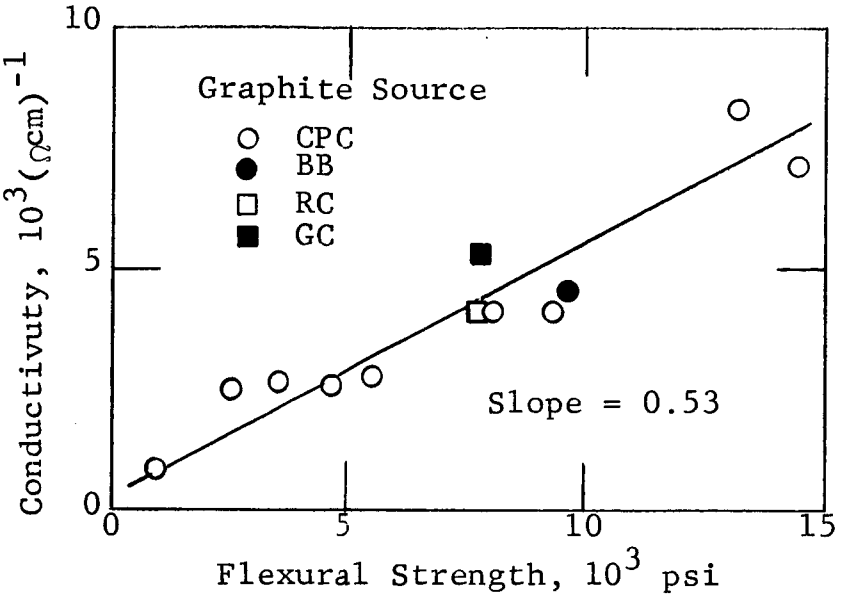


FIGURE 15: ELECTRICAL CONDUCTIVITY AS A FUNCTION OF FLEXURAL STRENGTH FOR MOLYBDENUM-GRAPHITE COMPOSITES

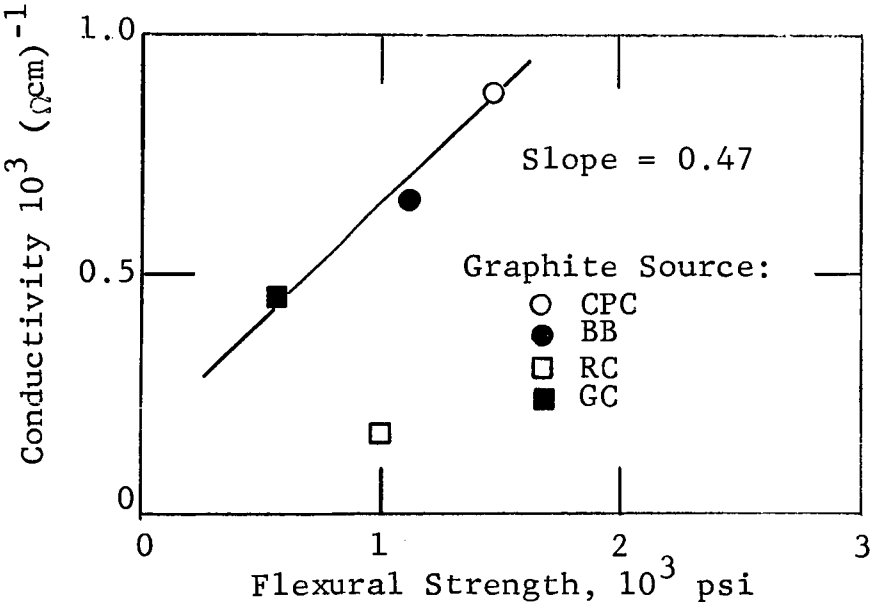


FIGURE 16: ELECTRICAL CONDUCTIVITY AS A FUNCTION OF FLEXURAL STRENGTH FOR GRAPHITE BODIES